A Forest Fire Sensor Web Concept with UAVSAR

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ABSTRACT

We developed a forest fire sensor web concept with a UAVSAR-based smart sensor and onboard automated response capability that will allow us to monitor fire progression based on coarse initial information provided by an external source. This autonomous disturbance detection and monitoring system combines the unique capabilities of imaging radar with high throughput onboard processing technology and onboard automated response capability based on specific science algorithms. In this forest fire sensor web scenario, a fire is initially located by MODIS/RapidFire or a ground-based fire observer. This information is transmitted to the UAVSAR onboard automated response system (CASPER). CASPER generates a flight plan to cover the alerted fire area and executes the flight plan. The onboard processor generates the fuel load map from raw radar data, used with wind and elevation information, predicts the likely fire progression. CASPER then autonomously alters the flight plan to track the fire progression, providing this information to the fire fighting team on the ground. We can also relay the precise fire location to other remote sensing assets with autonomous response capability such as Earth Observation-1 (EO-1)'s hyper-spectral imager to acquire the fire data.

I. INTRODUCTION

The series of recent wildfires in Southern California highlights the need for near-real time remote sensing data with high resolution wide coverage to help monitor and combat wildfires to reduce the loss of properties as well as forest carbon stocks. Following the fire, there is a need for rapid response to mitigate the threat of earth movement through debris flows and erosion causing loss of life and damaging property. Calibrated polarimetric radar imagery has been used to generate geophysical products such as flood plain, soil moisture, and fuel loading maps that provide valuable information during and following the fire. The unique capabilities of imaging radar to penetrate cloud cover and collect data in darkness over large areas at high resolution makes it a key information provider for the management and mitigation of natural and human-induced disasters such as earthquakes, volcanoes, landslides, floods, and wildfires. These capabilities are also vital in the exploration of planetary bodies such as Titan, Europa, and Venus. The challenges are its high raw data rate, requiring large onboard data storage and high downlink capability, and low data latency, requiring delivery of perishable information in time to be of use. This motivated us to develop an autonomous disturbance detection and monitoring system with UAVSAR.

Real time onboard synthetic aperture radar (SAR) processor development [1] is the first step towards reducing the downlink data rate. High fidelity polarimetric and interferometric SAR (InSAR) processing technology will reduce the downlink data rate by hundreds of orders of magnitude. The addition of onboard decision making and automated response capabilities will enable us to vary the data collection rate and retarget data acquisition on the fly. This smart sensor technology is directly applicable to future decadal space flight missions such as SMAP, DESDnyI, SWOT, and SCLP where different science algorithms can be used for a variety of disturbances.

In this paper, we will briefly overview the UAVSAR instrument and the onboard processor development. We will present the forest fire sensor web concept, its development challenges, and our sensor web verification plan.

II. UAVSAR

The fully polarized, L-band UAVSAR instrument had its genesis in NASA's Earth Science Technology Office Instrument Incubator Program and, after 2.5 years of development, it has successfully collected science data. System design was motivated by solid earth applications where repeat pass radar interferometry can be used to measure subtle deformation of the Earth's surface. The system has been designed with portability and extensibility as primary factors. Initial flights and laboratory testing of the instrument indicates it meets its instrument and science requirements. Flight tests provided the first science data from UAVSAR that will produce surface deformation maps with increased temporal and spatial resolution compared with existing spaceborne sensors. With future upgrades, UAVSAR will be able to support the science community beyond solid earth, cryosphere, and land cover applications. By designing the radar to be housed in an external unpressurized pod, it has the potential to be readily ported to other platforms, although initial testing is being carried out with the NASA Gulfstream III aircraft. The G-III has been modified for the radar pod and the aircraft has been equipped with Precision Autopilot capability developed by NASA Dryden Flight Research Center to fly the aircraft within a 10 m diameter tube of any specified trajectory necessary for repeat pass radar interferometric applications. To maintain the required pointing for repeat pass interferometric applications we have employed an actively scanned antenna that is steered based on inertial navigation measurement data. This system is the first civilian SAR to incorporate an electronically scanned array.

III. FOREST FIRE SENSOR WEB CONCEPT

One particular application of this real time sensor is to aid in wildfire management and control. Figure 1 shows the detection and response architecture of an Open Geospatial Consortium (OGC) compliant forest fire sensor web. Our goal is to provide critical information for rapid response during a forest fire. This forest fire sensor web is for UAVSAR to trigger on a forest fire alert, plan data acquisition with UAVSAR, collect radar data over the fire site, process data onboard to generate appropriate data products such as fuel load map, downlink the time critical information to disaster response agencies. The onboard automated response capability can also trigger other observational assets to collect data over the fire site.

Major ecosystems of the world such as boreal and tropical forests, shrub-lands, grasslands, and savannas experience recurrent fires as a result of natural causes or human activities. Understanding fire behavior characteristics and planning for fire management requires maps showing the distribution of wildfire fuel loads at medium to fine spatial resolution across large landscapes. Wildfire simulation prediction models require spatial maps of canopy heights, canopy base height, crown bulk density, canopy biomass, and moisture content [2]. Historically, these inputs were estimated for coarse fuel model types from sparse inventory of forest structure at stand-level and from species-based algorithms at plot scale. Remote sensing technologies such as SAR and lidar have the potential of providing quantitative information in monitoring and measuring these forest fuel load components for fire management [3]. Additionally radar sensors from airborne platforms have the potential of providing near real-time quantitative information about the forest structure and biomass components that can be readily translated to meaningful fuel loads for fire management.

Figure 1 shows the basic flow of the OGC compliant forest fire sensor web:

1) An alert is generated by the forest fire observer or MODIS Rapid Fire service.
2) An alert is detected by sensor web.
3) An alert is passed to the onboard planner and UAVSAR observation request is generated.
4) UAVSAR observation is obtained.
5) Process data onboard to generate fuel load map.
6) Downlink information to Forest Services and disaster management authority.
7) Generate new alerts for other sensor observation assets (e.g. EO-1).
8) Plan new data takes for UAVSAR.
9) Repeat steps 4 through 8 until flight ends.

We are developing a UAVSAR-based smart sensor that will enable us to plug into this sensor web concept.

IV. SMART SENSOR DEVELOPMENT

The smart sensor development is implemented in four steps: the real-time high fidelity SAR processor, the onboard autonomy software, science data product generation, and the communication component. The real-time SAR processor hardware is a self-contained VME chassis with single board computers and FPGA processor boards, high-speed serial interfaces for data routing, and Ethernet connection for processor control [5]. The high fidelity SAR processor software is primarily based on algorithms developed for the repeat-pass UAVSAR ground processor with motion compensation and antenna beam steering capabilities. Due to the pipeline nature of the real-time SAR processor, we had to develop a Kalman filter-based real-time pre-processor to fuse the inertial navigation data and the precise differential GPS data to obtain a smooth and precise trajectory of the platform. The platform trajectory information is then used to compute presum, motion compensation, and azimuth compression parameters for the SAR processor.

For onboard autonomy software, we will utilize our experience from Autonomous Sciencecraft Experiment (ASE) onboard the New Millennium Earth Observation One spacecraft (EO-1) to implement automated disturbance detection and monitoring capability for forest fire applications. We will utilize the Continuous Activity Scheduling Planning Execution and Replanning (CASPER) software onboard UAVSAR as the main scheduler of data-taking activities. CASPER interfaces with UAVSAR's main operations systems, the Automatic Radar Controller (ARC) and the Radar Operator's Workstation (ROW), to monitor and task UAVSAR. CASPER also interfaces with UAVSAR's Flight Planning Software to generate valid and native flight plans. The autonomous response process flow is as follows:

1. Read the current flight plan.
2. Process a batch of Points-of-Interest (POIs) generated by fuel load map and weather predictions to determine the swath(s) for data acquisition.
3. Generate a new flight plan that will cover the new swath(s).
4. Merge new flight plan with existing flight plan in the ROW. This may require knowledge of current platform location and other platform-related constraints such as aircraft fuel, airspace clearance, pilot approval in the case of the G-III aircraft, etc.

For science data product generation, radiometric and polarimetric calibrations are applied to the high resolution SAR imagery followed by geolocation of the imagery to an equi-angular surface. We then estimate the forest fuel load from the polarimetric data channels. The existing processor hardware has the capability to process two polarization channels in real time and we plan to process HH (horizontal transmit, horizontal receive) and HV (horizontal transmit, vertical receive) channels for forest fire application. Therefore, radiometric and polarimetric calibration methodology will have to rely on a priori knowledge of the radar hardware instead of the traditional approach of deriving cross talk and phase correction parameters from all four polarization channels, which are not readily available from the real-time SAR processor.

As for forest fuel load estimation, we used L-band polarimetric SAR imagery acquired over a large area of Yellowstone National Park (YNP) by AIRSAR to estimate the distribution of forest biomass and canopy fuel loads. Semi-empirical algorithms were developed to estimate crown and stem biomass and three major fuel load parameters, namely: 1) canopy fuel weight, 2) canopy bulk density, and 3) foliage moisture content. These estimates, when compared directly to measurements made at plot and stand levels, provided more than 70% accuracy and, when partitioned into fuel load classes, provided more than 85% accuracy [4]. Since we only have LHH and LHV channels for the current UAVSAR onboard processor, we plan to modify the empirical algorithms to use only these two polarization channels to determine the utility of the resultant science products. For forest fire fighting applications, we are more interested in the relative fuel load distribution in the immediate fire area rather than the absolute fuel load of the forest.

There are three main components to the communication infrastructure onboard the UAVSAR. The first communication link is the one that receives high rate raw radar data from the UAVSAR data acquisition controller and pipes the data into the real-time onboard SAR processor. This is accomplished by a PCI-based custom interface card [5]. The second component is the communication link between CASPER and UAVSAR's ARC or ROW to update flight plans. This is accomplished via Ethernet. The last component facilitates the receipt of external Sensor Alert Service (SAS) and external Sensor Observation Service (SOS) such as weather information as well as the transmission of science data products generated by the UAVSAR smart sensor to the end user on the ground. We plan to utilize the Iridium satellite phone service onboard the G-III to communicate with a single ground interface for this purpose. We will send and receive UDP packets via the phone modem at an estimated data rate of 2 kbps. This should be sufficient bandwidth for sending forest fuel load maps of 30 m posting. We plan to conduct an experiment to verify the sustainable data transfer rate with this approach in early summer.

V. SENSOR WEB VALIDATION PLAN

We plan to validate the forest fire sensor web concept through the following three steps:

1) Acquire sample forestry data in Southern California with UAVSAR to validate the fidelity of the real-time SAR processor and science algorithms used for forest fuel load map generation.
2) Use UAVSAR to demonstrate a closed loop smart sensor concept by retasking UAVSAR in flight based on results generated by the onboard SAR processor.
3) Use UAVSAR as an element of a larger sensor web, including the EO-1 Hyperion (hyperspectral imager), IKHANA AMS (Autonomous Modular Scanner, a thermal-infrared imaging system developed at Ames), and ground weather stations to demonstrate the forest fire sensor web concept.

VI. DEVELOPMENT STATUS

We are half way through our 3-year smart sensor development effort. Thus far we have focused most of our efforts on the development of the real-time SAR processor and this is due to be completed by the end of year 2. We have also developed the interface between the onboard autonomy software (CASPER) and UAVSAR's flight planning software. We are developing the communication infrastructure so that we can demonstrate the ability to generate real-time SAR imagery with live UAVSAR data and transmit the result down to the ground. We plan to acquire sample forestry data in Southern California with UAVSAR this summer to validate the fidelity of the real-time SAR processor and science algorithms used for forest fuel load map generation. In year 3, we will focus on the development of science data product generation and retasking of UAVSAR with science triggers. This will enable us to demonstrate the closed loop smart sensor concept. Once this concept is verified, we will be ready to demonstrate the use of UAVSAR as an element of a larger sensor web.

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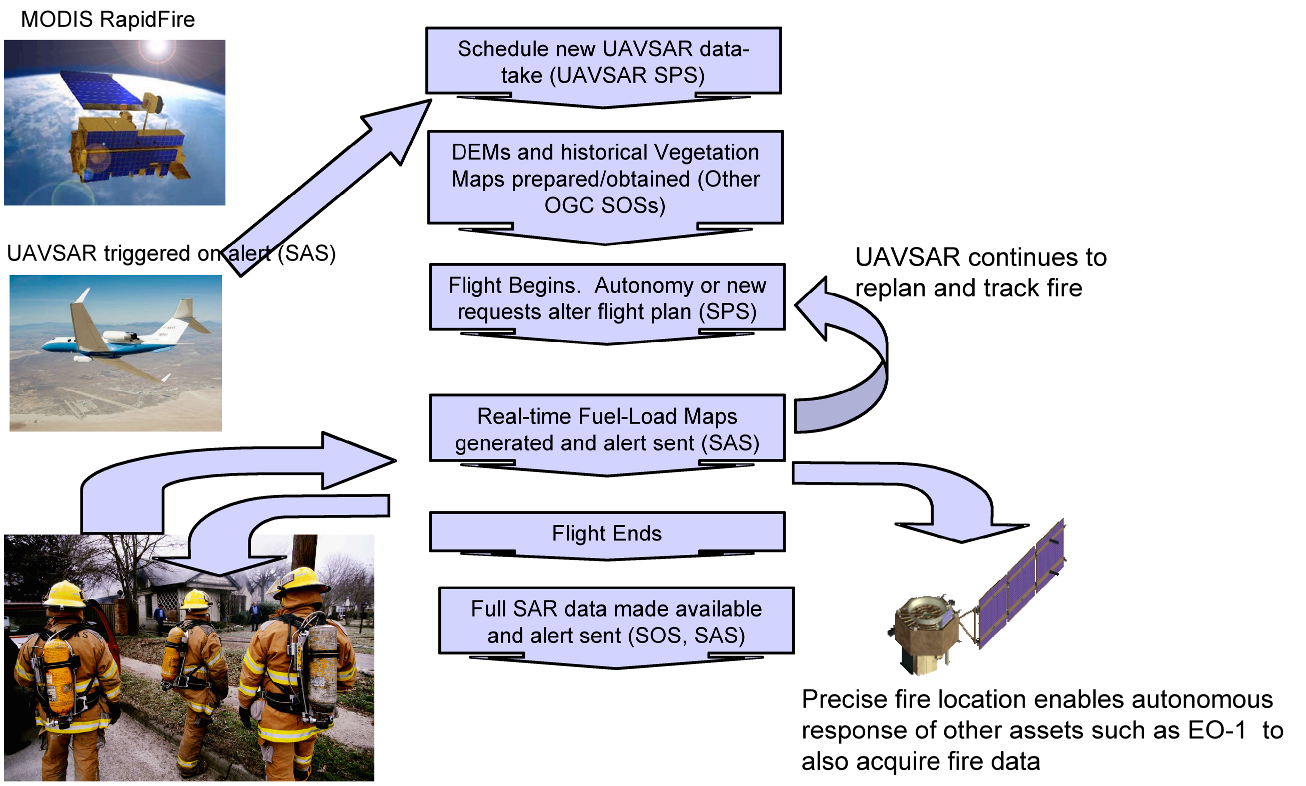

Figure 1. An OGC compliant forest fire sensor web concept with UAVSAR. MODIS RapidFire provides the Sensor Alert Service (SAS). UAVSAR's onboard autonomy software provides the Sensor Planning Service (SPS) whereas the UAVSAR instrument itself provides the requested observation data sets known as the Sensor Observation Service (SOS). UAVSAR onboard processor will provide the Sensor Alert Service by generating an alert to the firefighters or other remote sensing assets based on results of science data processing. This process continues until the flight ends.